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Blunt Criterion trauma model for head and chest injury risk assessment of cal. 380 R and cal. 22 long blank cartridge actuated gundog retrieval devices

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ABSTRACT

Background: Blunt ballistic impact trauma is a current research topic due to the widespread use of kinetic energy munitions in law enforcement. In the civilian setting, an automatic dummy launcher has recently been identified as source of blunt impact trauma. However, there is no data on the injury risk of conventional dummy launchers. It is the aim of this investigation to predict potential impact injury to the human head and chest on the basis of the Blunt Criterion which is an energy based blunt trauma model to assess vulnerability to blunt weapons, projectile impacts, and behind-armor-exposures.
Methods: Based on experimentally investigated kinetic parameters, the injury risk of two commercially available gundog retrieval devices (Waidwerk Telebock, Germany; Turner Richards, United Kingdom) was assessed using the Blunt Criterion trauma model for blunt ballistic impact trauma to the head and chest.
Results: Assessing chest impact, the Blunt Criterion values for both shooting devices were higher than the critical Blunt Criterion value of 0.37, which represents a 50% risk of sustaining a thoracic skeletal injury of AIS 2 (moderate injury) or AIS 3 (serious injury). The maximum Blunt Criterion value (1.106) was higher than the Blunt Criterion value corresponding to AIS 4 (severe injury).

With regard to the impact injury risk to the head, both devices surpass by far the critical Blunt Criterion value of 1.61, which represents a 50% risk of skull fracture. Highest Blunt Criterion values were measured for the Turner Richards Launcher (2.884) corresponding to a risk of skull fracture of higher than 80%.
Conclusion: Even though the classification as non-guns by legal authorities might implicate harmlessness, the Blunt Criterion trauma model illustrates the hazardous potential of these shooting devices. The Blunt Criterion trauma model links the laboratory findings to the impact injury patterns of the head and chest that might be expected.

1. Introduction

Blunt ballistic impact trauma is a current focus of research that has become more significant mainly due to the widespread use of kinetic energy munitions in law enforcement for incapacitating or restraining dangerous individuals or control riot crowds [1,2]. The erroneous belief that these mistakenly so called "non-lethal" or "less than lethal" munitions might be harmless has frequently been refuted [3,4].

Human response to impact trauma is subject to variation. Therefore, mathematical trauma models are used to predict injury from laboratory findings. The Blunt Criterion (BC) is an energy based model developed by Sturdivan at the Army's Biophysics Lab at Aberdeen Proving Ground, Maryland, and used within the U.S. Department of Defense to assess vulnerability to blunt weapons, projectile impacts, and behind-armor-exposures [5].

In the civilian setting, blank cartridge actuated dummy launchers have recently been recognized as previously unnoticed source of blunt ballistic impact trauma [6]. Blank cartridge actuated dummy launchers are used by waterfowl or migratory bird hunters to educate gundogs in retrieving downed birds. A dummy launcher is a tool for teaching and reinforcing the hunting situation by tying together the sound of a bang with the propelling of a hard foam dummy which marks a bird in the sky. The mode of operation of these conventional dummy launchers is pretty simple

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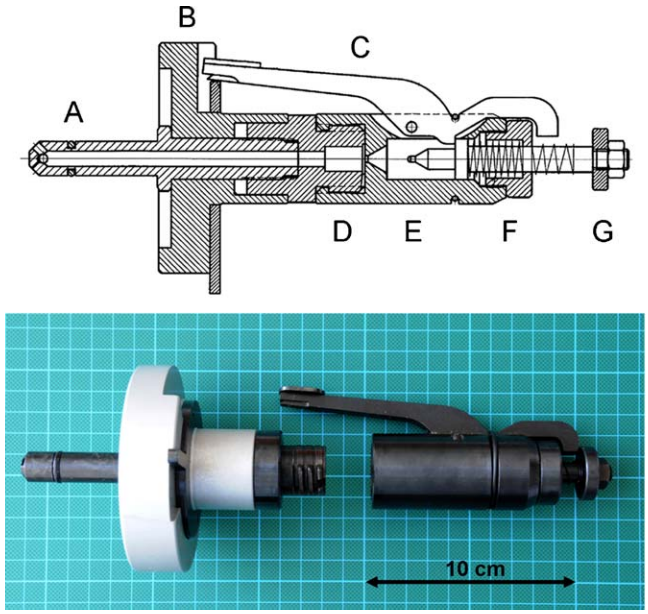

Fig. 1. Waidwerk Telebock Launcher. Spigot (outer diameter 13 mm, length from base of cartridge chamber 140 mm) with four pressure vent holes (A), launcher disk with drop safety device (B), trigger bar (C), cartridge chamber (D), firing pin (E), firing pin spring (F), and firing pin pull knob (G).

(Figs. 1 and 2). These conventional dummy launchers initially have been developed in the United Kingdom. Since decades, they are used at gundog trials and so called working tests throughout the world.

Controlled laboratory studies are necessary to estimate the dangers posed by different shooting devices. Also or even more if these devices are not generally known [7–9].

Therefore, it is the aim of this study to assess the risk of injury of two conventional gundog retrieval devices and to predict potential impact injury to the human head and chest on the basis of the energy based Blunt Criterion.

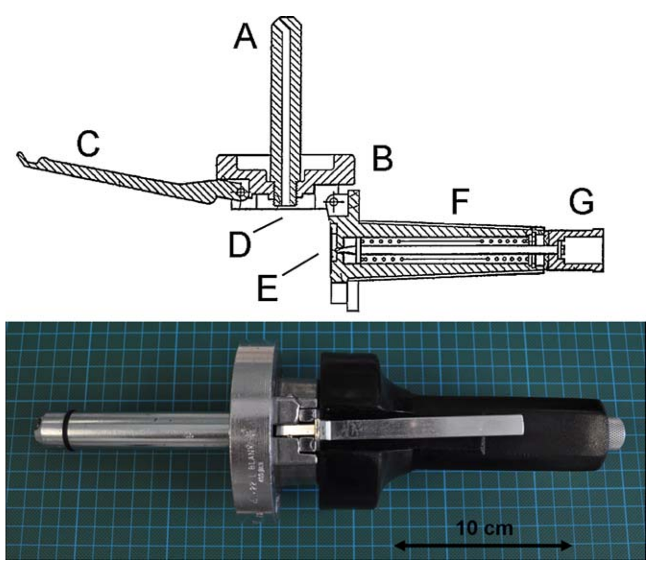

Fig. 2. Turner Richards Launcher. Spigot (outer diameter 19 mm, length from base of cartridge chamber 130 mm) with one pressure vent hole (A), hinge mechanism (B), breech locking lever (C), cartridge chamber (D), firing pin (E), handle (F), and firing pin pull knob (G).

Fig. 3. Left: 380 R blanc centerfire cartridge (Waidwerk Telebock Launcher). Right: 22 long blanc rimfire cartridge (Turner Richards Launcher).

2. Materials and methods

2.1. Test set-up for the ballistic experiments

Kinetic parameters of retrieval dummies propelled from two commercially available dummy launchers (Waidwerk Telebock, cal. 380 R blanc, Bretzfeld, Germany; Turner Richards, cal. 22 long blanc, Birmingham, United Kingdom) (Figs. 1 and 2) were measured with a high precision redundant ballistic speed measurement system between 1.0 m and 2.0 m from the muzzle (Dual-BMC 21a system and Dual-LS 1000 lightbarrier, Werner Mehl Kurzzeitmesstechnik, Diebach, Germany). This distance from the muzzle was chosen to avoid any measuring failure due to the gas jet streaming out of the muzzle.

Different commercially available cal. 380 R blanc centerfire cartridges (Umarex, Arnsberg, Germany; RWS Dynamit Nobel, Fuerth, Germany) and cal. 22 long blanc rimfire cartridges (Turner Richards, Birmingham, United Kingdom; Umarex, Arnsberg, Germany; RWS Dynamit Nobel, Fuerth, Germany) were used for test shots (Fig. 3). These blank cartridges are legally assigned for the use in these dummy launching devices. All cartridges were taken from one ammunition lot.

The incompressible dummies used for the test shots were as delivered with the particular shooting device. While the Waidwerk Telebock dummy launcher propels an ellipsoid hard-foam dummy, the Turner Richards dummy launcher propels a conical PVC dummy (Fig. 4).

Ten measurements were taken in each subtest and averaged. Measurements were taken in a completely enclosed indoor shooting test stand to avoid any weather influences.

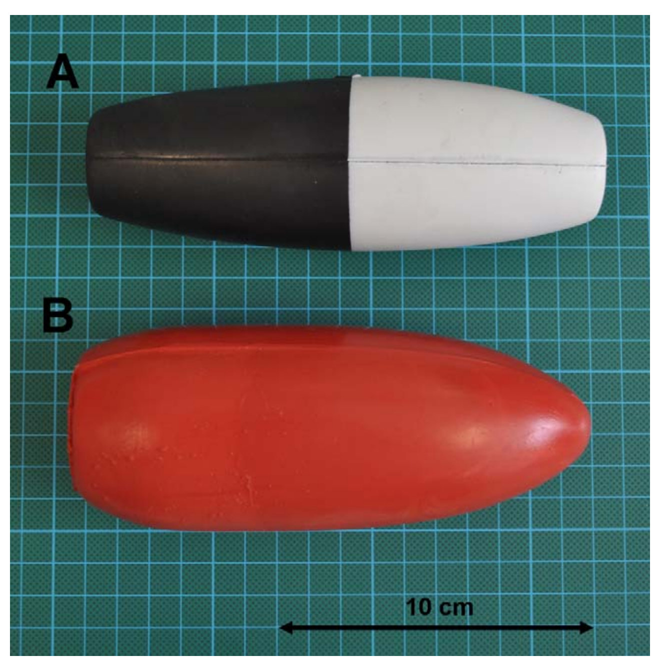

Fig. 4. (A) Waidwerk Telebock hard foam dummy (mass $m = 137.44$ g, length $l = 150$ mm, max. diameter $d = 50$ mm). (B) Turner Richards PVC torpedo dummy (mass $m = 233.47$ g, length $l = 160$ mm, max. diameter $d = 58$ mm).

2.2. Data analysis and processing

The mean velocity ± standard deviation for 10 shots was calculated. Momentum (p) was calculated as $p = m \times v$. Kinetic energy (E) was calculated as $E = 0.5 \times m \times v^2$.

To determine the wounding potential of the dummies assuming a lengthwise (axial) impact of the dummy head, the energy density (E') was calculated using energy and projectile's face area (A) [10].

Descriptive analysis suggested a normal distribution of data. The measurements of the different shooting devices/ammunition types were compared using the Student's t-test. A probability value of less than 5% ($p < 0.05$) was considered to be significant. Statistical analysis was performed using SPSS 16.0.1 (SPSS, Chicago, IL).

2.3. Injury risk assessment using the Blunt Criterion

The Blunt Criterion parameter used to predict injury risk is defined by the following equation:

$$BC = \ln[(1/2 \times M \times v^2)/(W^{1/3} \times T \times D)] \quad (1)$$

where M is the mass of the projectile in kilograms, v the velocity of the projectile in meters per second, W the mass of the struck individual in kilograms, T the combined thickness of the body wall at the impact location of the struck individual in centimeters, and D is the diameter of the projectile in centimetres [5].

As observed from the equation, the numerator of the equation represents the projectile's kinetic energy. In fact, it represents the kinetic energy deforming the body on impact and excludes the energy remaining in the impactor and transferred to the body as whole body motion. The denominator contains those characteristics of the target that have been found to be related to its ability to tolerate the energy of impact [11].

For anthropometric characteristics of the human head and chest as potential target, data corresponding to the anthropometric data of the 50th percentile male (body weight 77 kg) was used. Proportions of the total body mass represented by the different body parts (head, thorax) were calculated according to Sturdivan et al. and Pignolet et al. [5,12]. While data on the combined thickness of soft tissue and skull was derived from anthropometric literature, chest wall thickness (T) was estimated on the basis of the method of Sturdivan et al., where $T = k \times W^{1/3}$ and k is 0.711 for male subjects [5].

Therefore, the following values were used for calculating the Blunt Criterion: W_{Head} (average mass of the head) = 4.9 kg [12]; T_{Head} (average combined thickness of the soft tissue and skull) = 1 cm [13–15]; W_{Chest} (average mass of the thorax) = 16.2 kg [12]; T_{Chest} (average combined thickness of the soft tissue and ribs) = 3 cm [11].

Previous investigators considered the diameter of the impactor in relation to the thickness of the body wall struck by the impactor to be an important input parameter in the Blunt Criterion trauma model [5,11,16]. When a small, blunt object hits the body, the area of contact is just the cross-sectional area of the projectile. As the size of the projectile increases, the area of contact is determined by the curvature of the projectile and the body part struck. Therefore, Sturdivan introduced a correction for the effective diameter (D) of the projectile when D' is greater than twice the thickness of the body wall ($2 \times T$) [5]. Geometry gives the area of contact, A:

$$A = \pi \times T(D' - T); \quad D' > 2 \times T \quad (2)$$

The effective diameter (D) to be used in Eq (1) is

$$D = 2 \times \left(\frac{A}{\pi}\right)^{1/2} \quad (3)$$

Eq. (3) is used only when D' is greater than $2 \times T$. Otherwise, the actual diameter ($D' = D$) is used. Therefore, we corrected for the effective diameter only when calculating the Blunt Criterion for head impacts. For impacts to the chest we used the actual diameter of the projectiles.

Sturdivan has used the abbreviation "BC" for Blunt Criterion in his original publication. However, this abbreviation is widely used in the field of ballistics for the term "Ballistic coefficient". To avoid misunderstanding, we use "BTC" which stands for "Blunt Trauma Criterion" instead of "BC" as abbreviation of Sturdivan's original Blunt Criterion.

3. Results

3.1. Ballistic parameters of the Waidwerk Telebock Dummy Launcher

The Waidwerk Telebock Launcher obtained significantly higher ballistic parameters with the Umarex cartridges than with the RWS cartridges. Maximum average velocity of the Waidwerk Telebock Launcher was measured $v = 31.21$ m/s.

3.2. Ballistic parameters of the Turner Richards dummy launcher

The Turner Richards Launcher obtained highest ballistic parameters with the Turner Richards blank cartridges followed by the RWS and Umarex cartridges. Maximum average velocity of the Turner Richards Launcher was measured $v = 33.79$ m/s.

3.3. Blunt Criterion for risk assessment of head and chest injury

For both shooting devices and all ammunition combinations, each average value of the BTC_{Head} was higher than 1.6. Highest average BTC_{Head} values were obtained with the Turner Richards Launcher loaded with the cal. 22 long Turner Richards cartridges.

Highest average BTC_{Chest} values were also obtained with the Turner Richards Launcher loaded with the Turner Richards cartridges. Lowest average BTC_{Chest} values were obtained with the Turner Richards Launcher loaded with the Umarex cartridges.

For all parameters, differences between the launchers and the different ammunition types were statistically significant ($p < 0.0001$). For detailed experimental data see Table 1.

4. Discussion

Upon legal consideration, the dummy launcher is not a shotgun in its proper sense. Germany's Federal Criminal Police Office (Bundeskriminalamt, BKA) classifies the Waidwerk Telebock Launcher as non-gun [17]. Proof test mark and number are issued by the German National Proof House (Physikalisch-Technische-Bundesanstalt, PTB) [18]. In the United Kingdom, the Association of Chief Police Officer's (ACPO) Firearms and Explosives Licensing Working Group (FELWG) also classifies "Turner Richards type" dummy launchers as non-guns for the purposes of the relevant UK legislation [19]. The Turner Richards Launcher bears the "BNP (British Nitro Proof) under crown" proof test mark issued by the Birmingham Proof House. Due to the reciprocal acceptance of approval test marks both shooting devices are also approved by the C.I.P. member states [20]. In the U.S., cal. 22 blanc dummy launchers identical in construction to the Turner Richards Launcher are common and widely used.

Previous studies have shown that the impact event and the biomechanical response of the human being to blunt ballistic impacts are different from previous automotive research [11]. The maximum peak force for the blunt ballistic impact to the human thorax was found to be much higher in comparison to automotive impacts [11]. The duration of blunt ballistic impact is much shorter than the impact event in automotive research (0.5–2 ms vs. 40–

Table 1
Experimental data. Each 10 shots were averaged. Standard deviations (SD) are presented in brackets.

Launcher/ammunition	Velocity v (m/s)	Impulse p (Ns)	Energy E (J)	Energy density E' (J/mm^2)	Blunt Criterion BTC/head[a]	Blunt Criterion BTC/chest
Waidwerk Telebock/Umarex .380 R	31.21 (SD ± 0.88)	4.289 (SD ± 0.121)	66.97(SD ± 3.80)	0.034 (SD ± 0.002)	2.287 (SD ± 0.056)	0.566 (SD ± 0.056)
Waidwerk Telebock/RWS .380 R	28.82 (SD ± 0.25)	3.960 (SD ± 0.035)	57.06 (SD ± 1.01)	0.029 (SD ± 0.001)	2.128 (SD ± 0.018)	0.408 (SD ± 0.178)
Turner Richards/TR .22 long	33.79 (SD ± 1.37)	7.888 (SD ± 0.320)	133.46 (SD ± 10.46)	0.051 (SD ± 0.004)	2.884 (SD ± 0.084)	1.106 (SD ± 0.084)
Turner Richards/RWS .22 long	20.31 (SD ± 1.21)	4.742 (SD ± 0.282)	48.31 (SD ± 5.74)	0.018 (SD ± 0.002)	1.864 (SD ± 0.119)	0.086 (SD ± 0.119)
Turner Richards/Umarex .22 long	17.85 (SD ± 0.68)	4.166 (SD ± 0.158)	37.22 (SD ± 2.80)	0.014 (SD ± 0.001)	1.607 (SD ± 0.077)	−0.170 (SD ± 0.077)

[a] As $D > 2 \times T$, the effective diameter of the projectiles was adjusted according to Eqs. (2) and (3).

60 ms) [11,21]. The mean peak force in blunt ballistic impact to the head is reached in less than 0.6 ms [22].

Previous efforts to determine the risk of injury of blunt ballistic impact focused primarily on kinetic energy [23,24]. Current research on behind body-armor blunt trauma considers residual impact energy values of 70 J for the chest impact and 25 J for the head impact as threshold values for severe blunt trauma [25,26].

Despite a strong correlation between experimentally measured kinetic energy and the risk of injury, a recent study demonstrated the higher predictive ability of the Blunt Criterion for blunt thoracic injury in comparison with kinetic energy [5].

Sturdivan et al. investigated the value of the Blunt Criterion to express the probability of producing injury at all levels of injury severity determined by the Abbreviated Injury Scale (AIS) [5]. While the maximum BTC_{Chest} value of the Waidwerk Launcher (BTC_{Chest} = 0.566) corresponds to AIS 3 (serious injury) according to the data of Sturdivan et al., the maximum BTC_{Chest} value of the Turner Richards Launcher is higher than the BTC corresponding to AIS 4 (severe injury) (Table 1) [5]. Bir and Viano also investigated the risk of thoracic injury due to blunt ballistic impact. On the basis of their results, a BTC_{Chest} of 0.37 will result in a 50% chance of sustaining a thoracic skeletal injury of AIS 2 (moderate injury) or AIS 3 (serious injury) [3]. They also observed that a 50% chance of AIS 2+ injury correlated to a kinetic energy of 67.8 J and corrected the previously set tolerance of 78.7 J. However, comparability of the data is limited as the Blunt Criterion was validated by Bir and Viano using the whole body mass whereas the effective mass of the body part struck by the impactor was used in our study.

In a recent study, the BTC also proved to be the best indicator of fracture for the assessment of skull fracture risk for blunt ballistic temporo-parietal head impact. Based on logistic regression models, a 50% risk of skull fracture is represented by a BTC_{Head} of 1.61 [27]. Based on these regression curves, the skull fracture risk due to the dummies investigated in this study can be estimated to be higher than 80% (represented by a BTC_{Head} of 2.0) for the Waidwerk Telebock (loaded both with the RWS and the Umarex ammunition) and for the Turner Richards Launcher loaded with the Turner Richards ammunition. The skull fracture risk can be estimated to be higher than 50% (represented by a BTC_{Head} of 1.61) for the Turner Richards Launcher loaded with the RWS and the Umarex ammunition. A study assessing the biomechanic response of the head to blunt ballistic impact determined the zygoma/maxilla most susceptible to being fractured [21].

Energy density (E') of all test shots was below the threshold energy density required for skin penetration ($E'_{TSH} = 0.1\ \mathrm{J/mm^2}$) [23,28]. The area of contact is determined by the curvature of the object, therefore, for a conically shaped dummy, the first contact is at a point of zero area [5]. Thus, energy density at this first contact point might even exceed the threshold energy density of the skin.

The spigot of the Waidwerk Telebock Launcher is almost identical to the one of the Röhm Rapid Launcher which is a multishot cartridge actuated (9 mm PAK) dummy launcher based on a modified blank handgun. The ballistic parameters of this device, which uses an almost identical dummy, have recently been reported [6]. However, the energy delivered to the dummy by the Waidwerk Telebock in the present investigation is much higher than the energy of the dummy launched by the Röhm Rapid Launcher [6]. While the length and the diameter of the launcher arm are identical in both devices, the launcher arm of the Röhm Rapid Launcher is pinned and welded to the barrel imitation which increases the distance between cartridge chamber and muzzle. As previous investigations have shown, shortening the barrel vastly increases the gas pressure at the muzzle [29]. This effect has also been observed in blank gas or alarm weapons. Kneubuehl differentiates blank firing weapons into short-barrelled blank weapons with a high energy density of the gas jet at the muzzle and blank weapons bearing a long barrel imitation (barrel length >120 mm for pistols and >135 mm for revolvers) resulting in a lower energy density of the gas jet at the muzzle [30]. With regard to the different blank cartridges used in both devices, Kneubuehl measured approximately twice the gas pressure for the 380 R blanc calibre compared with the 9 mm PAK calibre [30].

The corresponding studies on the injury response to blunt impact cited above have been done using human cadavers. It is generally accepted to use unembalmed human cadavers as surrogate as the lack of muscle tone is not a limiting factor in the use of cadavers for impact testing [31]. On the other hand, cadaveric specimens lack physiologic responses and therefore cannot demonstrate such injuries as arrhythmias, traumatic apnea, bruising, and cerebral contusion [11]. Although uncommon, deaths from cardiac fibrillation following blunt ballistic impact to the chest (commotio cordis) might occur with trauma that would otherwise not be called severe and that might not be accompanied by other pathological findings of the thorax [32].

The Sturdivan formula is very sensitive to the thickness of the body wall of the individual struck by the impactor. Particularly with respect to forensic facial reconstruction, there are numerous anthropometric studies on facial soft tissue and skull thickness [13–15]. However, assessment of the chest wall thickness is a difficult task. Similar to Sturdivan's prediction equation, previous efforts in the field of emergency medicine or radiation safety to experimentally determine the chest wall thickness developed empirical equations relating chest wall thickness to functions of anatomical parameters such as weight and height [33–35]. However, population-based data on the chest wall thickness over the cardiac silhouette is lacking. This anatomic region is at particular risk for blunt thoracic impact trauma [36,37].

In contrast to the Turner Richards dummy launcher, the firing mechanism of the Waidwerk Telebock dummy launcher features a drop safety device to prevent unintentional discharge when the launcher is dropped or roughly handled.

5. Conclusion

The classification as non-guns by legal authorities must not implicate harmlessness as demonstrated by the injury patterns of the head and chest that might be expected.

Therefore, it is incumbent upon emergency physicians and forensic experts alike to have a working knowledge of the variety of injuries that may be caused by cartridge actuated shooting devices.

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